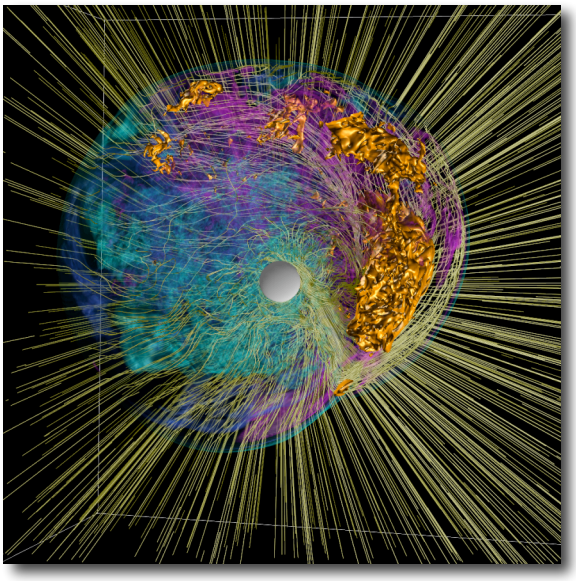
How are pulsars born?

Anthony Mezzacappa (ORNL)

Core collapse supernovae are stellar explosions, the death throes of massive stars with mass greater than ten times the mass of the Sun. They result from the collapse of their iron cores. This collapse produces a shock wave that moves through the star to produce the spectacular explosion that obliterates the star almost entirely, leaving behind only a remnant proto-neutron star. The proto-neutron star will go on to form a neutron star or black hole. If the neutron star is left spinning, it can become a pulsar. Radiation is generated by the magnetic fields surrounding the neutron star, and if it is spinning, this radiation is seen on Earth when the radiation direction and our line of sight match, much like observing the light from a lighthouse. How the neutron star is made to spin is an open question. During the supernova explosion, the stellar core behaves like a fluid. Recent three-dimensional hydrodynamics simulations by John Blondin (NCSU) and Anthony Mezzacappa (ORNL) on the Leadership Computing Facility at ORNL have shown that the proto-neutron star may be made to spin by the stellar core flow above it as the supernova explosion is generated. The supernova shock wave leads to two counter rotating flows beneath it, one directly beneath the shock wave moving in a clockwise rotation with respect to a particular line of sight and another, deeper flow directly above the proto-neutron star moving in the opposite direction. The material above the proto-neutron star is not ejected in the supernova and settles onto the proto-neutron star, thereby causing it to spin. Young pulsars are observed to spin with periods between 15 and 300 milliseconds. The Blondin-Mezzacappa models predict spin periods in this range: 50 milliseconds. This proposed mechanism for the birth of pulsars comes at a time when there are no other explanations consistent with observations. In the previously held theory, pulsar spin results from the dramatic increase of the initial rotation of the star's core as it collapses, much like ice skaters spin faster as they pull their arms closer to their bodies. However, this theory predicts spin periods far too rapid to be consistent with observations. The results of this study have been published in *Nature* [Blondin and Mezzacappa, *Nature*, **445**, 58 (2007)].



Snapshot of the counter rotating flows below the shock wave in a three-dimensional simulation of a core collapse supernova. The fluid and fluid streamlines are shown. One flow, directly beneath the shock (the surface in the image) is moving in a clockwise direction. A counterclockwise rotating flow near the proto-neutron star at the center (the silver sphere) is also evident. [Image by Kwan-Liu Ma (UC Davis).]